Composition Analysis of Pork Carcasses by Dual-Energy X-Ray Absorptiometry[1,2]

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ABSTRACT: Dual-energy x-ray absorptiometry (DXA) was used as a noninvasive method to measure the composition of pig carcasses. A total of 181 half-carcasses (10 to 51 kg, from pigs slaughtered at approximately 30, 60, 90, and 120 kg) were scanned using a Lunar (Madison, WI) DPX-L densitometer. The DXA measurements of fat, lean, bone mineral, and total tissue mass were compared with chemical analysis for fat, water, protein, total ash, and scale weight. The mean value for total tissue mass by DXA was slightly less than the mean carcass weight (32.3 kg vs 33.6 kg, $P > .05$, $R^2 = .998$). Although highly correlated ($R^2 = .81$), the DXA measurement of the percentage of fat in the half-carcass was less ($P < .001$) than the chemical measurement (19.5 vs 24.9%). The DXA measurement of lean tissue mass (total mass less fat and bone mineral) was correlated with carcass protein ($R^2 = .97$) and water ($R^2 = .99$) content. The correlation (R^2) between DXA bone mineral content and carcass ash content was only .68; however, DXA bone mineral content was more highly correlated with carcass weight ($R^2 = .93$) than was carcass ash content ($R^2 = .70$). When we used the DXA R value (ratio of the attenuation coefficients for fat and lean) to predict percentage of fat in the carcass, the mean value for predicted carcass fat was 25.9% ($P > .05$). Similarly, carcass protein and water content were predicted from DXA lean. Using DXA region of interest analysis, estimates of the fat content of the shoulder and ham regions were close to chemical values; however, DXA underestimated the fat content of the loin and side regions by 20 and 28%, respectively. When prediction equations were used to evaluate DXA measurements of the half-carcasses of 28 gilts and 37 boars slaughtered at approximately 120 kg, the half-carcasses of gilts contained more fat (33.9 vs 27.8%, $P < .001$), less protein (14.1 vs 16.1%, $P < .001$), and less water (45.9 vs 52.1%, $P < .001$) than those of boars. These results indicate that DXA could be a valuable research tool for measuring the composition of pig carcasses. On the basis of the results of this study, prediction equations were revised for the DXA estimation of fat, protein, and water content of the half-carcass: Fat (%) = 450 – (315 · DXA R value), Protein (g) = –145 + (.23 · DXA lean), and Water (g) = 150 + (.73 · DXA lean). Furthermore, it seems that separate prediction equations are needed for regional analysis.

Key Words: Pigs, Carcass Composition, X-rays

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Introduction

Even though a number of methods are available (Kauffman and Warner, 1993), the ability to quickly and accurately estimate the composition of pork carcasses continues to challenge both the researcher and the meat industry in general. The major objectives of new methodologies are to avoid the inaccuracies of the "quick-and-easy" methods and to provide a more convenient technique than dissection or chemical analysis, which continue to be the standards by which other methods are measured.

Among the new methods that have been evaluated for measuring carcass composition in the research setting, computerized tomography and magnetic resonance imaging offer accuracy and the ability to provide detailed information. Unfortunately, both of these methods are expensive and time-consuming, and they require considerable technical expertise. X-ray attenuation or absorptiometry is the basis for a commonly used instrument (Anyl-Ray, BWI Kartridg-Pak, Davenport, Iowa) for measuring the lean:fat

[1]Mention of a trade name does not constitute a guarantee or warranty by the USDA and does not imply its approval to the exclusion of other products that may be suitable.

[2]We express our appreciation to N. Faulkner for her technical assistance.

Received October 23, 1997.

Accepted March 30, 1998.

ratio of meat products. In principle, the measurement of fat or lean by x-ray absorptiometry is based on the greater attenuation of the x-rays by lean (water and protein) than by fat. Furthermore, the x-ray is greatly attenuated by bone or ash, and, for that reason, the Anyl-Ray is used only for ground meat with little or no bone present. However, dual-energy x-ray absorptiometry (**DXA**) scans the sample at two x-ray energy levels (i.e., 38 and 70 keV), which provided a two-dimensional image and measurements of bone mineral, fat and lean content, and total tissue mass. In other studies, DXA has been used to measure the body composition of live pigs (Brunton et al., 1993; Svendsen et al., 1993; Mitchell et al., 1996a,b; Pintauro et al., 1996; Mitchell and Scholz, 1997). The purpose of the present study was to investigate DXA as a research method for measuring the fat, lean, and bone mineral content of pork carcasses.

Experimental Procedures

A total of 181 half-carcasses ranging in weight from 10 to 51 kg were obtained from pigs slaughtered at approximately 30 (n = 18), 50 (n = 24), 60 (n = 16), 90 (n = 58), or 120 kg (n = 65). At slaughter, the head and viscera were removed, and the carcass was split at the midline. The hair and feet remained on the carcass. The right half of each carcass was chilled for 24 h, weighed, and then scanned using a Lunar (Madison, WI) DPX-L densitometer. The scan mode was determined by the carcass weight. Carcasses weighing less than 30 kg (pigs slaughtered at live weights of 30 to 60 kg) were scanned using the pediatric-small or medium mode, whereas carcasses weighing more than 30 kg (pigs slaughtered at live weights of 90 to 120 kg) were scanned using the adult-medium mode. The basic theory and methodology for measuring body composition by DXA is similar to that for DPA (dual energy photon absorptiometry), which has been described in detail (Peppler and Mazess, 1981; Gotfredsen et al., 1984). Briefly, the measurement of composition by the DXA system used in this study is based on the differential attenuation of low- (38 keV) and high-energy (70 keV) x-rays by fat and other soft tissues. The fat and lean content is determined for each pixel (.46 cm^2) of a total body scan that does not overlie bone. The soft tissue that is occluded by bone is assumed to have the same composition as the average for the soft tissue on either side. The soft tissue attenuation ratio ($\mathbf{R_{st}}$) is the ratio of the mass attenuation coefficients (μ) (Gotfredsen et al., 1986) at 38 and 70 keV. Calibration studies at DPX energies of 38 and 70 keV report that R_{st} values range from 1.2 for fat to 1.4 for 100% lean. The DXA instrument in this study used the pencil beam technology, which scans at line intervals of 9 mm. Scan times for the half-carcasses ranged from 5 to 12 min, depending on carcass size. The DXA total body results provided measurements of fat, lean, bone mineral, and total tissue mass. After the DXA scan was performed, each carcass was homogenized by grinding as described previously (Mitchell et al., 1994). Homogenized tissue samples were analyzed for fat content by chloroform-methanol extraction (Folch et al., 1957) (CV = .9%), protein by Kjeldahl nitrogen determination (CV = 2.4%), and water by lyophilization (CV = 1.9%). To compare DXA bone mineral content to total carcass ash by combustion, the total carcass ash content was corrected for the ash content of .85% for boneless pork meat (Jebb et al., 1995).

The DPX-L (adult mode) software allows manual regional analysis, which provides fat, lean, bone mineral, and total tissue mass for each user-defined region. Using this option, the DXA scan results were analyzed by dividing the carcass into four regions: ham, shoulder, loin, and side. An example of a typical image produced from the DXA scan is shown in Figure 1, where the outline of the four manual regions of interest can also be seen. In an attempt to validate the regional analysis results, 30 of the carcasses weighing an average of 34.2 kg were dissected, as closely as possible, along the same lines as described for the DXA regional analysis. These individual regions were ground and analyzed as described above for the whole carcass. The following prediction equations (Mitchell et al., 1996c) were used for conversion of DXA values:

$$\text{Fat (\%)} = 535 - (377 \cdot \text{R value}) \quad (R^2 = .85,\ \text{SE of the estimate} = 1.82)$$

$$\text{Protein (g)} = -33.9 + (.217 \cdot \text{DXA lean}) \quad (R^2 = .97,\ \text{SE of the estimate} = 272)$$

$$\text{Water (g)} = 981 + (.678 \cdot \text{DXA lean}) \quad (R^2 = .99,\ \text{SE of the estimate} = 421)$$

From 117 of the half-carcasses, area of the longissimus muscle (**LM**) was determined at the level of the 10th rib, fat thickness (**P2BF**) over the LM was measured at 65 mm from the midline, and average backfat (**ABF**) thickness was determined from midline measurements at the first and last ribs and at the last lumbar vertebra.

Statistical analysis was performed using Statgraphics® procedures (STSC, 1992). Comparisons of DXA and chemical measurements of carcass composition were based on linear regression analysis and *t*-test comparison of the means. The use of DXA to determine differences in carcass composition based on gender and genotype differences was evaluated by analysis of variance. Simple correlation procedure was used to relate ABF, P2BF, and LM measurements to DXA and chemical measurements of fat and lean.

Results and Discussion

Weight. One of the unique features of the DXA measurement is the report of total weight or tissue

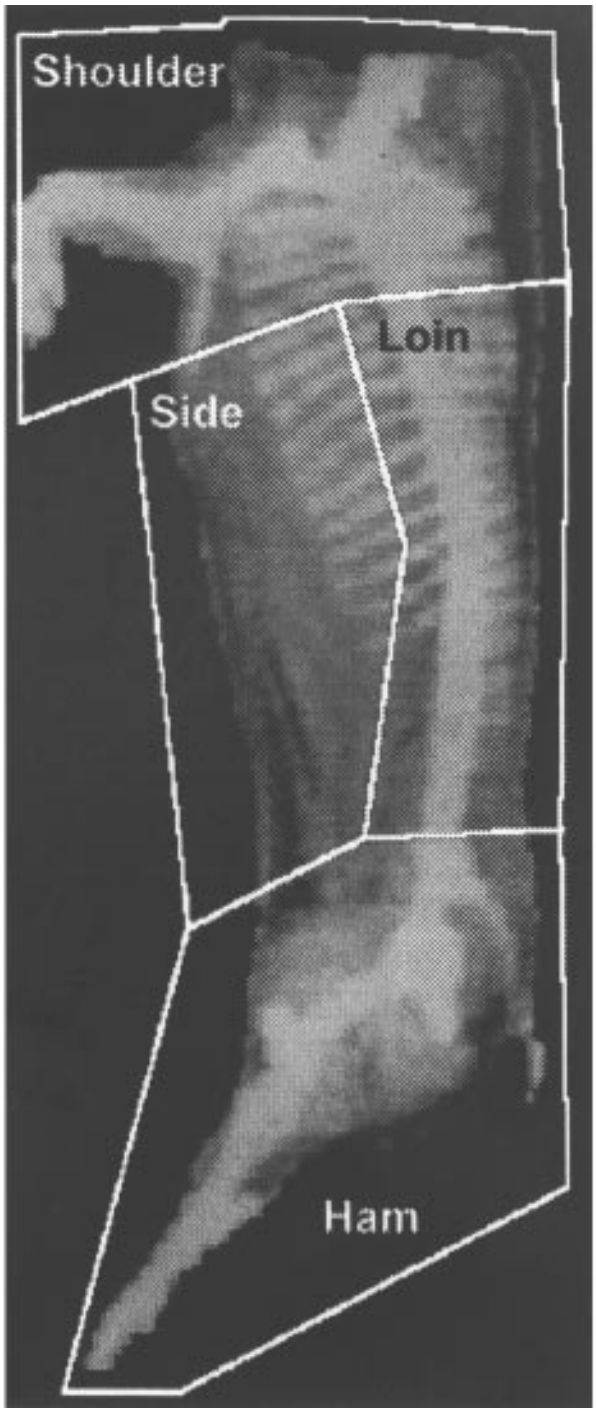

Figure 1. Dual-energy x-ray absorptiometry (DXA) scan of a pig half-carcass. Lines shown on scan were used to define the shoulder, ham, loin, and side regions for manual region of interest analysis.

mass. The DXA weight measurement is derived as a summation of its measurements of fat, lean, and bone mineral masses. Although there are quicker and easier means (i.e., weighing the carcass) for obtaining a measurement of total mass, it is nevertheless important because it means that the DXA values for composition are independent of a separate measurement of carcass weight. A good agreement between DXA total mass and carcass weight indicates that the sampling or total amount of tissue detected by DXA was acceptable as long as there was no bias with regard to a particular type of tissue. However, as pointed out by Roubenoff et al. (1993), the accurate measurement of weight by DXA is a necessary condition for the operation of the instrument, but it is not evidence that it will accurately predict fat, lean, or bone mineral, which is a function of how DXA classifies the tissues based on the attenuation of the x-ray energies.

The mean DXA value for the total tissue mass for all half-carcasses was 4% less than the mean weight of the half-carcass measured by scales (Table 1). Although not significant, this difference persisted through the weight groups, indicating a relatively constant underestimation of tissue mass (1,381 ± 489 g). When analyzed by individual weight groups, the weights of all groups were less ($P < 0.01$) than the scale weights. The difference between DXA and scale weight ranged from 8.9% for half-carcasses from the 30-kg pigs to 2.9% for half-carcasses from the 50- and 120-kg pigs.

Total Carcass Fat. Of most concern in pork production, and therefore the most critical measurement of carcass composition by DXA, is the amount of fat in the carcass. The mean DXA value for the fat content of the half-carcasses was 21.7% lower than the mean value determined by chemical analysis (Table 1). The DXA measurement of percentage fat in the tissue is a function of the DXA R value, which is the ratio of the mass attenuation coefficients at the two DXA energy levels (38 and 70 keV). The relationship between DXA R values and the DXA and chemical measurements of percentage fat in the half-carcass is shown in Figure 2. There apparently was a closer agreement between DXA and chemical values for carcasses containing a higher percentage of fat. Only at fat contents above 30 to 35% was there an acceptable agreement between DXA and chemical analysis. Also in Figure 2 can be seen the separate results of half-carcasses scanned using the pediatric mode (smaller half-carcasses, 9.8 to 27.1 kg) and those scanned using the adult mode (larger half-carcasses, 31.9 to 51.3 kg). Thus, the discrepancy between DXA and chemical measurements of percentage fat may be a function of fat content and sample size. The ratio of DXA fat to chemical fat was used as a measure of the accuracy of the DXA fat value. Regression analysis revealed a higher correlation of the accuracy of DXA values with carcass weight ($R^2 = .40$) than with the percentage of fat in the carcass ($R^2 = .27$). The higher R^2 indicates that weight accounts for a greater percentage of the variability in accuracy than does percentage of fat.

A preliminary evaluation of the use of DXA for measuring composition of the pork half-carcass indi-

Table 1. Comparison of dual-energy x-ray absorptiometry (DXA) and chemical (CHEM) analysis of pork half-carcass composition

Item	DXA[a]	CHEM[a]	Difference[b]	*P*	R^2	SEE[c]
Direct						
Weight, kg	32.27 ± 11.14	33.65 ± 11.29	–1.38 ± .49	.24	.99	.427
Fat, %	19.49 ± 7.41	24.89 ± 5.85	–5.39 ± 3.37	.001	.80	2.59
Fat, kg	6.89 ± 4.18	8.81 ± 4.18	–1.93 ± 1.18	.001	.92	1.17
Lean, %	74.06 ± 6.52	71.07 ± 5.75	2.98 ± 2.73	.001	.80	2.58
Lean, kg	24.45 ± 7.44	23.44 ± 7.21	1.01 ± 1.39	.18	.98	1.00
BMC, %	2.83 ± .28	2.56 ± .57	.27 ± .57	.001	.03	.56
BMC, kg	.93 ± .37	.85 ± .33	.08 ± .20	.026	.68	.18
Estimated[d]						
Fat, %	25.95 ± 6.32	24.89 ± 5.85	1.06 ± 2.60	.10	.82	2.49
Fat, kg	9.29 ± 4.61	8.81 ± 4.18	.48 ± .99	.31	.96	.85
Protein, %	16.19 ± 1.45	16.46 ± 1.23	–.27 ± 1.05	.054	.49	.88
Protein, kg	5.34 ± 1.62	5.47 ± 1.75	–.13 ± .39	.48	.95	.38
Water, %	53.68 ± 5.64	54.60 ± 4.81	–.92 ± 2.18	.10	.85	1.83
Water, kg	17.56 ± 5.05	17.97 ± 5.48	–.41 ± .86	.46	.98	.77

[a]Mean ± SD, n = 181.
[b]DXA – CHEM ± SD.
[c]SEE = standard error of the estimate.
[d]Fat, protein, and water contents were estimated using the following equations (Mitchell et al., 1996c): Fat (%) = 535 – (377 · R value), Protein (g) = –33.9 + (.217 · DXA Lean), Water (g) = 981 + (.678 · DXA Lean).

cated inaccuracy of DXA for measuring fat content (Mitchell et al., 1996c). Using the previously reported regression equation (Mitchell et al., 1996c) for predicting percentage of fat from the DXA R value resulted in a mean value that was 4.2% greater than the chemical measurement (Table 1). Based on the present study, the equation for predicting percentage of fat from the DXA R value was revised as follows:

$$\text{Fat (\%)} = 450 - (315 \cdot \text{DXA R value})$$

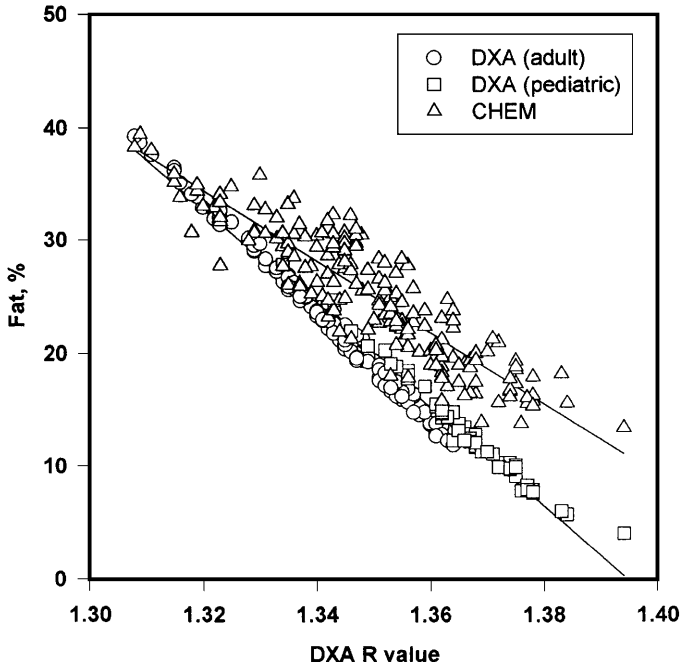

Figure 2. Relationship between the dual-energy x-ray absorptiometry (DXA) R value (ratio of soft tissue attenuation coefficients) and the percentage fat in the pork half-carcass reported by DXA analysis or the percentage of fat determined by chemical analysis.

Figure 3 compares the predicted results using this revised equation to the results obtained by chemical analysis.

Carcass Lean, Protein, and Water. The DXA procedure does not provide a direct measure of either muscle mass or protein content, but rather of lean tissue, which is a composite of many components, exclusive of fat and bone mineral. Correspondingly, chemical analysis did not provide a measure of lean tissue mass; therefore, it was computed as the sum of total carcass protein (N × 6.25) and water. The summation of the chemical determinations of fat, water, protein, and ash accounted for 99.1 ± 1.6% of the total weight of the half-carcass.

The DXA measurement of lean mass was 4.3% greater than the lean mass measured by chemical analysis. When expressed as a percentage of carcass weight, the DXA measurement was greater ($P < .001$) than the chemical measurement. Using the previously reported equation (Mitchell et al., 1996c) to predict protein content from DXA lean resulted in a mean value that was only 2.4% less than the value obtained by chemical analysis. The prediction equation for estimating the protein content of the half-carcass from DXA lean was revised as follows:

$$\text{Protein (g)} = -145 + (0.23 \cdot \text{DXA lean})$$

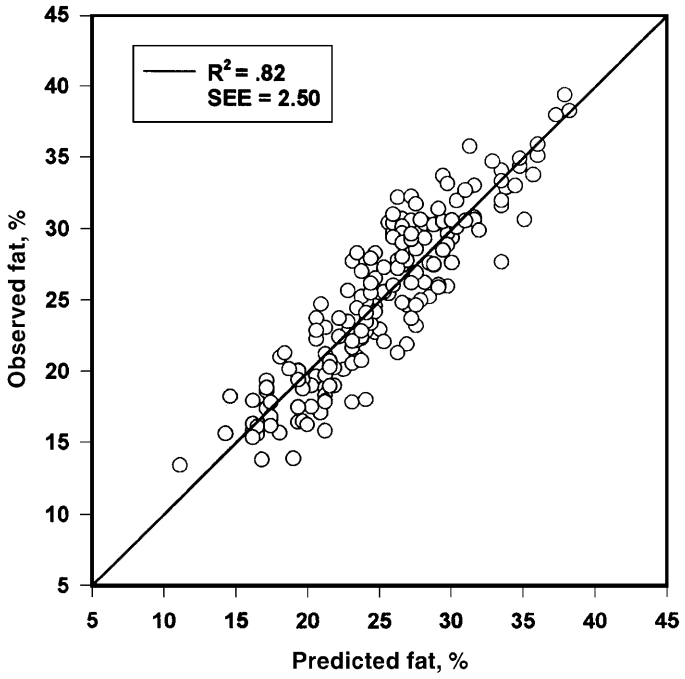

Figure 3. Relationship between the percentage fat in the pork half-carcass as predicted from the dual-energy x-ray absorptiometry (DXA) R value [% fat = 450 – (315 · R value)] and the observed percentage fat (chemical analysis).

Figure 4 compares the predicted results using this revised equation to the results that were observed by chemical analysis.

Water, which is the major component of the lean tissue mass, was estimated using the DXA lean value (Mitchell et al., 1996c). This estimation resulted in a mean value for water content of the half-carcass that was 2.3% less than the amount based on chemical analysis. Based on the results of this study, the prediction equation was also revised for the DXA estimation of water. The revised equation is as follows:

$$\text{Water (g)} = 150 + (.73 \cdot \text{DXA lean})$$

The relationship between the percentage of water in the half-carcass that was predicted using the revised DXA equation and the amount determined by chemical analysis is shown in Figure 5. The relationships for the observed and predicted values for percentages of fat, protein, and water that are presented in Figures 3, 4, and 5, respectively, indicate that for fat and water there was a close fit between observed and predicted values. However, for protein there was still considerable deviation of the observed from predicted values. Dramatic changes in tissue hydration during early development may seriously influence interpretation of DXA measurement of soft tissue composition. McMeekan (1940) reported that the water content of subcutaneous adipose tissue of pigs was 84.9% at birth and dropped to 19.5% by 4 wk of age and 4.9% at 28 wk, whereas the lipid content increased from 6.2% at birth to 75.4% at 4 wk and 92.4% at 28 wk. Kauffman et al. (1964) observed that the protein:water ratio in pork muscle increased rapidly from .156 at birth to .297 at 3.5 mo of age. Assuming that the attenuation of the x-ray beam by lipid vs water is not affected by how these two components are dispersed throughout the tissue, tissue hydration would be expected to have little effect on the DXA assessment of fat content. Alternatively, changes in the hydration of adipose and muscle tissue would have significant influence on how the DXA lean mass measurement is allocated between water and protein. The protein:water ratio of the half-carcasses measured in this study increased with increasing carcass weight and percentage fat. The ratio was lower ($P < .05$) in the carcasses of pigs slaughtered at 30 or 50 kg than in carcasses of those slaughtered at 60, 90, or 120 kg (.285 and .291 vs .303, .306, and .308, respectively). However, the correlation was higher between the protein:water ratio and percentage of fat ($R^2 = .25$) than between the protein:water ratio and carcass weight ($R^2 = .15$).

Normally, the carcasses of market-weight pigs are of fairly uniform maturity, and, consequently, the protein content would be a relatively constant proportion of the carcass lean mass. However, the inclusion

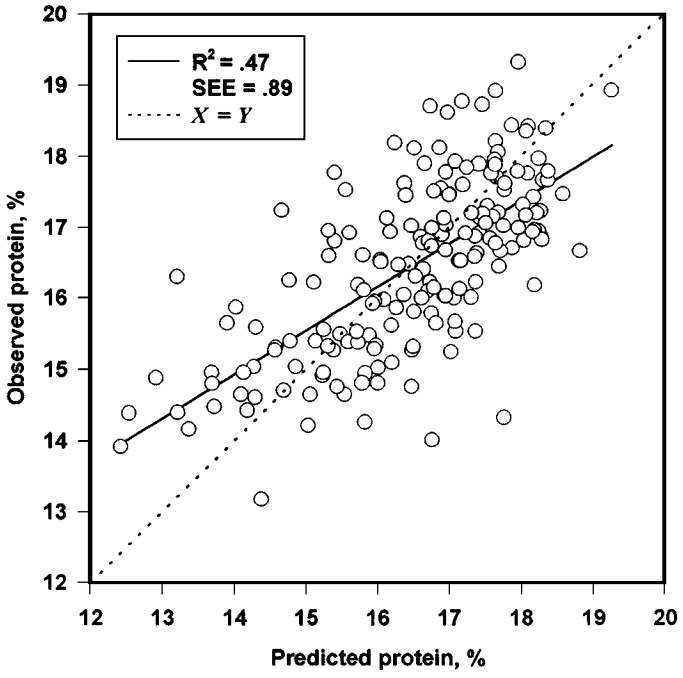

Figure 4. Relationship between the percentage protein in the pork half-carcass as predicted from dual-energy x-ray absorptiometry (DXA) lean mass measurement [protein (g) = (–145) + (.23 · DXA lean)] and the observed percentage protein (chemical analysis, protein = N · 6.25). (SEE = SE of the estimate).

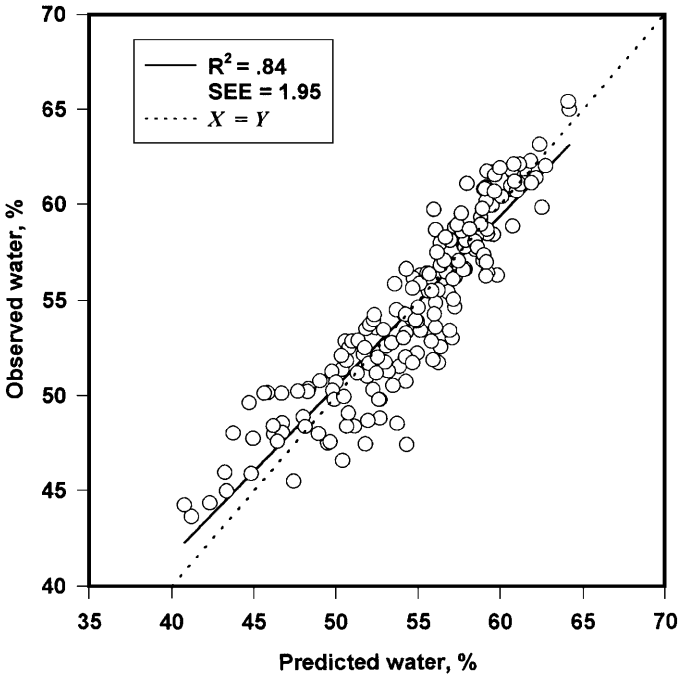

Figure 5. Relationship between the percentage water in the pork half-carcass as predicted from dual-energy x-ray absorptiometry (DXA) lean mass measurement [water (g) = 150 + (.73 · DXA lean)] and the observed percentage water (chemical analysis). (SEE = SE of the estimate).

of the carcasses of younger pigs (slaughtered at 30, 50, or 60 kg live BW) could explain the discrepancies shown in Figure 4. The increased hydration in young pigs could result in an underestimation of protein content based on the DXA lean measurement. Because water is a much larger component of the lean mass, the relative effect on estimation of total body water would be considerably less than for total body protein. Therefore, corrections based on age or possibly on weight may be needed if DXA is to be used to predict the percentage of protein in the carcasses of pigs slaughtered over a wide range in age.

Bone Mineral or Carcass Ash. Because bone constitutes a relatively constant nonedible portion of the carcass and because determination of the bone content of the carcass by dissection is very labor-intensive, it is frequently not considered in carcass composition measurements. However, when treatments might result in changes in bone growth, it becomes important to be able to determine total carcass bone content. The DXA procedure, in contrast, is reported to provide a rapid and accurate measure of total bone mineral content and is most noted for its ability to measure bone density (Lukaski, 1993).

The mean DXA value for the bone mineral content (**BMC**) measurement of all carcasses was 9.4% more than the amount estimated from the ash content of the half-carcass (Table 1), but it was 9% less than the total ash content of the half-carcass. However, it should be noted that considerable variation is encountered in performing carcass ash analysis and is a possible source of error (Ellis et al., 1994), but such variation would not necessarily explain the difference between DXA and chemical analysis.

Regional Analysis. A traditional method of measuring pork carcass composition involves dissecting the carcass into primal cuts: shoulder, loin, side, and ham. By using the manual region of interest analysis option available with the DPX-L total body software, it was possible to partition the DXA scan into four regions that approximate the four primal cuts. An example of the four regions that were defined by DXA manual region of interest analysis are shown in Figure 1.

The results of DXA and dissection/chemical analysis for the four carcass regions are shown in Table 2. The mean DXA value for total tissue mass for this group of 30 carcasses was 5.1% less than the scale weight ($P <$ .001). When partitioned into regions, DXA tissue mass measurements for the shoulder, ham, loin, and side were 5.8, 3.6, .7, and 11.1% less than the scale weights following dissection. Only the DXA measurement of the loin region was not ($P = .68$) different from the weight of the dissected region. The low variation in weights resulting from the narrow range of carcass weights included in this group undoubtedly contributed to the low R^2 values that were observed. However, there was a closer agreement between DXA and dissected values for the ham and shoulder regions than was previously reported for scans of live pigs (Mitchell et al., 1996a). Positioning differences and better definition of anatomical markers permitted an easier match between DXA and dissection. However, definition across soft tissue areas was still a likely source of error.

There was good agreement between DXA and chemical analysis for the percentage of fat in the shoulder region. The DXA estimate for the fat content of the ham region was 7.7% greater than the amount measured by chemical analysis. However, the greatest discrepancy was in the loin and side regions, where DXA underestimated the fat content by 20.3 and 28.0%, respectively, compared with chemical analysis. Consequently, DXA overestimated the lean content of the loin and side regions by 11.8 and 20.4%, respectively. The reason for the discrepancy between DXA and chemical measurements of the fat and lean content of the loin and side regions is not clear; however, tissue thickness may have been a factor. In particular, the side region was considerably thinner than the other regions and in some cases may have been less than 2.5 cm. The loin region is thicker than the side, but the accuracy of soft tissue evaluation for lean and fat content may be compromised by the large amount of bone that dominates the image field. Using the prediction equation described earlier for the half-carcass, the DXA measurement of total fat for the 30

Table 2. Comparison of dual-energy x-ray absorptiometry (DXA) and chemical (CHEM) analysis of the composition of pork half-carcass regions

Region	DXA[a]	CHEM[a]	Difference[b]	*P*	R^2	SEE[c]
Shoulder						
Weight, kg	9.96 ± .64	10.58 ± .64	–.62 ± .12	.001	.96	.12
Fat, %[d]	26.45 ± 2.52	27.02 ± 4.32	–.57 ± 3.73	.53	.24	3.84
Lean, %	71.41 ± 2.51	68.94 ± 4.47	2.47 ± 3.46	.010	.38	3.58
BMC, %	3.69 ± .27	2.91 ± .78	.74 ± .71	.001	.15	.73
Ham						
Weight, kg	10.11 ± .52	10.49 ± .49	–.38 ± .30	.05	.67	.29
Fat, %[d]	25.75 ± 2.62	23.90 ± 3.25	1.83 ± 2.61	.02	.37	2.62
Lean, %	72.19 ± 2.71	72.60 ± 3.11	–.41 ± 2.41	.59	.43	2.39
BMC, %	3.54 ± .33	2.65 ± .58	.90 ± .64	.001	.004	.59
Loin						
Weight, kg	7.33 ± .46	7.38 ± .47	–.05 ± .37	.68	.44	.36
Fat, %[d]	27.05 ± 2.92	33.94 ± 5.48	–6.88 ± 3.78	.001	.55	3.73
Lean, %	72.06 ± 2.76	64.46 ± 5.14	7.61 ± 3.09	.001	.72	2.75
BMC, %	2.41 ± .31	2.28 ± .55	.13 ± .42	.27	.40	.44
Side						
Weight, kg	5.03 ± .31	5.66 ± .42	–.63 ± .31	.001	.45	.32
Fat, %[d]	29.07 ± 3.37	40.35 ± 6.16	–11.29 ± 5.25	.001	.25	5.42
Lean, %	71.90 ± 3.16	59.72 ± 5.98	12.18 ± 4.41	.001	.45	4.48
BMC, %	.62 ± .19	.80 ± .37	–.19 ± .38	.02	.0006	.64

[a]Mean ± SD, n = 30.
[b]DXA – CHEM ± SD.
[c]SEE = standard error of the estimate.
[d]Percentage fat was estimated using the equation fat (%) = 465 – (325 · R value) (Mitchell and Scholz, 1995).

half-carcasses used for regional analysis was 8,639 g compared with the summation of 8,192 g when the same equation was applied to the four regions separately. This suggests that a separate prediction equation is needed for each of the four regions. Despite these discrepancies, Figure 6 shows that DXA reported linear increases in the fat content of each region as the DXA-measured fat content of the half-carcass increased. The rate of increase in fat content of the side and loin regions exceeded the rate of increase in the shoulder and ham regions and, in that regard, was consistent with the results of the chemical analysis.

The DXA measurements of BMC in the ham and shoulder regions were 33.9 and 25.4% greater than those calculated from the total ash content of the respective regions. Differences between DXA and chemical determination of BMC may be due to inaccuracies in ash measurements introduced by grinding and analyzing the regions separately. The sum of the ash content of the regions analyzed separately was 982 g compared with the ash content of 1,068 g measured from the contralateral half-carcass, whereas the DXA measurement of BMC was 928 g for both.

Evaluation of Sex Differences in Carcass Composition. The DXA procedure was used to evaluate differences in the composition of the carcasses of 29 boars and 36 gilts slaughtered at approximately 120 kg (Table 3). The DXA values for fat, protein, and

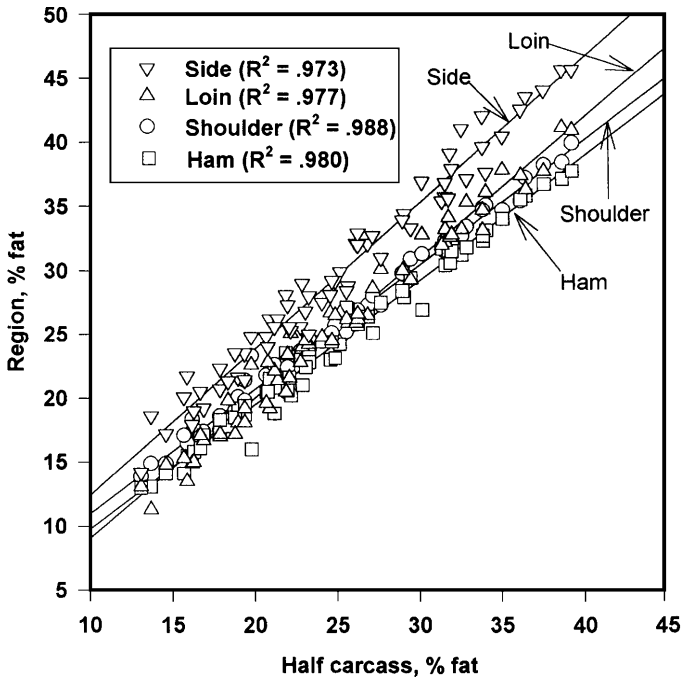

Figure 6. Relationship between the dual-energy x-ray absorptiometry (DXA) measurement of percentage fat in the half-carcass and the DXA measurements of percentage fat in the various regions (shoulder, ham, loin, and side) using the manual region of interest analysis.

Table 3. Evaluation of gender differences (boars vs gilts) in carcass composition comparing dual-energy x-ray absorptiometry (DXA) and dissection/chemical (CHEM) analysis[a]

	DXA		CHEM	
Item	Gilts (n = 29)	Boars (n = 36)	Gilts (n = 29)	Boars (n = 36)
Half-carcass				
Weight, kg	44.41 ± .31	43.91 ± .28	45.87 ± .32	45.14 ± .28
Fat, %[b]	32.46 ± .58	26.27 ± .52*	31.57 ± .69	25.07 ± .62*
Lean, %	64.46 ± .58	70.71 ± .52*	64.91 ± .91	70.77 ± .62*
Protein, %[c]	14.51 ± .20	16.69 ± .18*	15.49 ± .19	16.46 ± .17*
Water, %[c]	47.72 ± .64	54.37 ± .58*	49.42 ± .57	54.31 ± .52*
BMC, %[d]	3.08 ± .04	3.02 ± .03	3.00 ± .10	3.07 ± .09
Shoulder				
Weight, kg	13.43 ± .17	14.33 ± .15*		
Fat, %[b]	31.75 ± .57	26.12 ± .51*		
Lean, %	63.92 ± .59	69.87 ± .53*		
BMC, %[d]	4.32 ± .07	4.01 ± .06		
Ham				
Weight, kg	13.97 ± .13	14.00 ± .12		
Fat, %[b]	31.08 ± .53	25.13 ± .48*		
Lean, %	65.33 ± .55	71.48 ± .50*		
BMC, %[d]	3.59 ± .09	3.38 ± .08		
Loin				
Weight, kg	9.95 ± .16	9.23 ± .14*		
Fat, %[b]	32.02 ± .66	25.86 ± .60*		
Lean, %	65.21 ± .64	71.51 ± .58*		
BMC, %[d]	2.77 ± .06	2.63 ± .06		
Side				
Weight, kg	7.12 ± .12	6.37 ± .11*		
Fat, %[b]	35.10 ± .63	27.97 ± .57*		
Lean, %	64.37 ± .63	71.46 ± .56*		
BMC, %[d]	.53 ± .03	.57 ± .03		

[a]Mean ± SE.
[b]Percentage fat was estimated using the equation Fat (%) = 465 – (325 · R value) (Mitchell and Scholz, 1995).
[c]Percentages of protein and water were estimated using the equations Protein (g) = –33.9 + (.217 · DXA Lean) (Mitchell et al., 1996c) and Water (g) = 981 + (.678 · DXA Lean) (Mitchell et al., 1996c).
[d]BMC = bone mineral content.
*Significant ($P < .05$) difference between measurement for gilts and boars.

water were estimated using the revised prediction equations described above. The DXA results were consistent with chemical analysis, indicating that carcasses from gilts had a higher percentage of fat and lower percentages of protein and water. There was no difference between boars and gilts in bone mineral content of the half-carcass.

The DXA analysis was used to determine differences between boars and gilts within the shoulder, ham, loin, and side regions of the half-carcass. In all four regions, the carcasses from gilts contained more fat and less lean than did those from boars. Again, there was no difference in bone mineral content. Using the DXA measurements of tissue mass, the boars had larger shoulder and the gilts had larger loin and side regions, and there was no difference in the size of the ham region.

Evaluation of Genetic Differences in Carcass Composition. Presence of the halothane gene is known to be associated with differences in carcass composition (Aalhus et al., 1991; Pommier et al., 1992) and quality (Sather et al., 1991; Leach et al., 1996). Using the carcasses of a group of pigs slaughtered at approximately 90 kg, DXA was used to evaluate differences in composition of carcasses of pigs that were identified as homozygous positive (*nn*) or negative (*NN*) or heterozygous (*Nn*) with respect to the halothane gene (Table 4). The DXA procedure and chemical analysis indicated that carcasses from the *nn* pigs contained less fat, but more lean, protein, or water than the carcasses from the *NN* pigs. Intermediate values were observed by DXA and by chemical analysis for the *Nn* pigs; however, only chemical analysis indicated that the carcasses of this group also had more fat and less lean, protein, or water than the *nn* pigs. The DXA analysis by region indicated the same differences by genotype for the shoulder, ham, loin, and side as detected for the half-carcass. There were no differences in bone mineral

Table 4. Evaluation of genotype differences (homozygous positive, *nn*; negative, *NN*; or heterozygous, *Nn* for halothane gene) in carcass composition comparing dual energy x-ray absorptiometry (DXA) and dissection/chemical (CHEM) analysis[a]

	DXA			CHEM		
Item	*nn* (n = 5)	*Nn* (n = 6)	*NN* (n = 6)	*nn* (n = 5)	*Nn* (n = 6)	*NN* (n = 6)
Half-carcass						
Weight, kg	33.69 ± .62^{x}	33.93 ± .56^{x}	33.77 ± .56^{x}	35.50 ± .68^{x}	35.65 ± .62^{x}	35.63 ± .62^{x}
Fat, %[b]	22.02 ± .94^{x}	24.35 ± .86^{xy}	24.98 ± .86^{y}	21.32 ± 1.31^{x}	25.42 ± 1.20^{y}	27.48 ± 1.20^{y}
Lean, %	75.46 ± .92^{x}	73.12 ± .84^{xy}	72.44 ± .84^{y}	75.31 ± 1.09^{x}	69.79 ± 1.00^{y}	69.58 ± 1.00^{y}
Protein, %[c]	17.67 ± .30^{x}	16.91 ± .28^{xy}	16.58 ± .28^{y}	17.20 ± .36^{x}	15.57 ± .33^{y}	16.90 ± .33^{y}
Water, %[c]	57.85 ± .97^{x}	55.43 ± .89^{xy}	54.37 ± .89^{y}	58.11 ± .87^{x}	54.22 ± .79^{y}	52.67 ± .79^{y}
BMC, %[d]	2.52 ± .08^{x}	2.53 ± .08^{x}	2.57 ± .08^{x}	3.28 ± .35^{x}	3.02 ± .33^{x}	3.51 ± .33^{x}
Shoulder						
Weight, kg	10.63 ± .32^{x}	10.37 ± .29^{x}	10.22 ± .28^{x}	11.54 ± .34^{x}	11.69 ± .31^{x}	11.65 ± .31^{x}
Fat, %[b]	22.07 ± .82^{x}	24.34 ± .75^{xy}	24.81 ± .75^{y}			
Lean, %	75.01 ± .85^{x}	72.68 ± .77^{xy}	72.18 ± .77^{y}			
BMC, %[d]	2.92 ± .15^{x}	2.98 ± .14^{x}	3.01 ± .14^{x}			
Ham						
Weight, kg	10.82 ± .22^{x}	10.35 ± .20^{x}	10.43 ± .20^{x}	10.35 ± .21^{x}	9.56 ± .19^{y}	9.52 ± .19^{y}
Fat, %[b]	21.50 ± .81^{x}	23.60 ± .74^{xy}	24.12 ± .74^{y}			
Lean, %	76.33 ± .82^{x}	74.17 ± .75^{xy}	73.62 ± .75^{y}			
BMC, %[d]	2.17 ± .07^{x}	2.23 ± .06^{x}	2.25 ± .06^{x}			
Loin						
Weight, kg	6.00 ± .28^{x}	6.67 ± .25^{xy}	7.02 ± .25^{y}	6.40 ± .24^{x}	6.98 ± .22^{xy}	7.29 ± .22^{y}
Fat, %[b]	21.75 ± 1.18^{x}	24.23 ± 1.07^{xy}	25.18 ± 1.07^{y}			
Lean, %	75.57 ± 1.13^{x}	73.29 ± 1.03^{xy}	72.36 ± 1.03^{y}			
BMC, %[d]	2.68 ± .14^{x}	2.48 ± .13^{x}	2.46 ± .13^{x}			
Side						
Weight, kg	4.92 ± .29^{x}	5.11 ± .26^{x}	5.05 ± .26^{x}	5.27 ± .19	5.88 ± .17^{y}	6.05 ± .17^{y}
Fat, %[b]	23.08 ± 1.32^{x}	25.91 ± 1.21^{xy}	26.96 ± 1.21^{y}			
Lean, %	76.56 ± 1.30^{x}	73.67 ± 1.18^{xy}	72.64 ± 1.18^{y}			
BMC, %[d]	.36 ± .06^{x}	.42 ± .05^{x}	.40 ± .05^{x}			

[a]Mean ± SE.
[b]Percentage fat was estimated using the equation Fat (%) = 465 – (325 · R value) (Mitchell and Scholz, 1995).
[c]Percentages of protein and water were estimated using the equations Protein (g) =–33.9 + (.217 · DXA Lean) (Mitchell et al., 1996c) and Water (g) = 981 + (.678 · DXA Lean) (Mitchell et al., 1996c).
[d]BMC = bone mineral content.
[x,y]For DXA or CHEM analysis, genotype values followed by unlike superscripts were different at $P < .05$.

Table 5. Correlation (r) between carcass backfat or longissimus muscle measurements and chemical or dual-energy x-ray absorptiometry (DXA) analysis of carcass composition[a]

Carcass Composition	P2 backfat depth, mm	Average backfat depth, mm	Longissimus muscle area, cm^2
Chemical			
Fat, g	.707	.854	.385
Fat, %	.731	.841	.113 (NS)[b]
Lean, g	.371	.534	.713
Lean, %	–.725	–.847	–.052 (NS)
DXA			
Fat, g	.690	.818	.433
Fat, %	.753	.816	.170 (NS)
Lean, g	.380	.566	.691
Lean, %	–.752	–.811	–.174 (NS)

[a]n = 117.
[b]Not significant at $P < .05$.

content. The only difference in tissue mass measurement was a smaller loin weight for the *nn* pigs compared with the *NN* pigs. Using live animal real-time ultrasound scans, Cisneros et al. (1996) was able to detect halothane genotype differences in the carcass composition of *Nn* and *NN* pigs. However, the ultrasound tended to overestimate the lean content of the fatter carcasses from the *NN* pigs and underestimate the lean content of the leaner carcasses of the *Nn* pigs.

Relationship with Backfat and Longissimus Muscle Measurements. Longissimus muscle (LM) area and P2 backfat (P2BF) and average backfat (ABF) measurements were made on 117 of the half-carcasses. Correlation between LM, P2BF, or ABF and chemical or DXA analysis is shown in Table 5. The P2BF and ABF were highly correlated with chemical and DXA measurements of total and percentage fat in the half-carcass. However, the correlation between DXA and

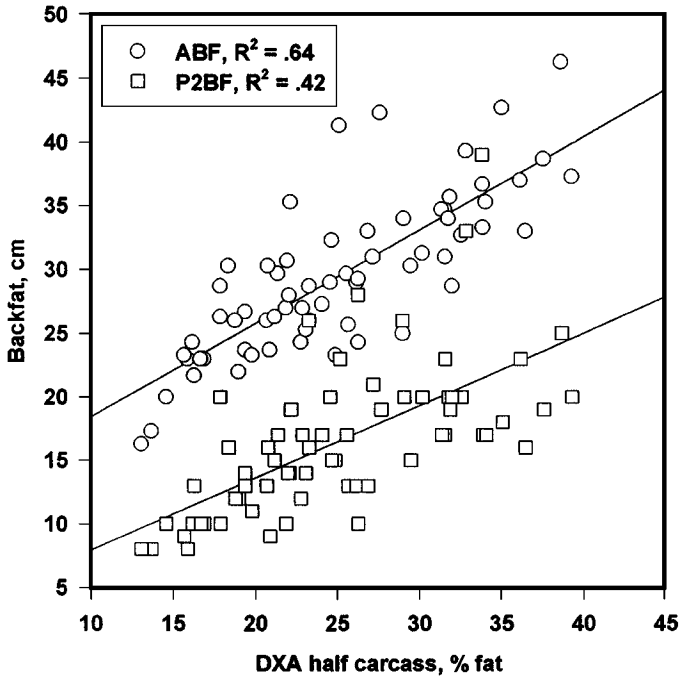

Figure 7. Relationship between the dual-energy x-ray absorptiometry (DXA) measurement of percentage fat in the half-carcass and the P2 backfat (P2BF) and average backfat (ABF) measurements.

chemical fat measurements (r = .96 and .87 for total and percentage fat, respectively) was higher than that for either P2BF or ABF and chemical fat. In Figure 7, the percentage of fat in the half-carcass based on DXA scans is compared with P2BF and ABF measurements. The LM area was correlated ($P < .05$) with chemical and DXA measurements of total lean content of the half-carcass, but not with percentage of lean by either chemical or DXA measurement. By contrast, DXA lean measurements were highly correlated with respective chemical measurements of total (r = .98) and percentage of lean (r = .86).

Implications

The results of this study indicate that dual energy x-ray absorptiometry can be used for determination of the fat, lean, and bone mineral content of pork half-carcasses. Even though the procedure is too slow for compatibility with on-line processing, for research purposes, compared with dissection or chemical analysis, it offers speed, simplicity, and potential accuracy. The present study demonstrates that dual energy x-ray absorptiometry is capable of detecting gender and genotype differences in carcass composition. Furthermore, improvements in accuracy are expected through refinement of prediction equations for half-carcass and for region of interest analyses.

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